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Resilience thinking: a brief overview

Nathanaël Pingault, Christopher Martius, CIFOR-ICRAF

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Introduction

Enhancing landscape resilience is gaining traction as a way to address a 'triple challenge': ensuring the well-being of a growing global human population, while mitigating and adapting to climate change, and reversing biodiversity loss and ecosystem degradation. Landscape resilience can be broadly understood as the capacity of a landscape to persist under changing conditions, adapting and transforming when necessary, in order to maintain its essential structure, functions and identity (IPCC 2022). Landscapes can be seen as spatially-bound, complex adaptive social-ecological systems (SES), where humans and nature interact (CE 2000; Walker and Salt 2006; Cumming et al. 2013). The term 'social-ecological system' emphasizes the integrated concept of "humans-in-nature" (Berkes and Folke 1998). It recalls that the social and ecological dimensions cannot be easily disentangled and that any distinction between them is somewhat artificial and arbitrary. Building on these definitions, this infobrief provides a short overview of the main concepts used in resilience theory.

1. Resilience: a multifaceted concept

The word 'resilience' (from the Latin verb *resilire*) means the capacity to bounce back, recover or spring forward in the face of adversity (Davoudi 2012). This concept has infused many disciplines over the last century, including psychology, mechanics and material science (Béné and Doyen 2018). Holling (1973) introduced the concept in ecology science and defined it as "the persistence of relationships within a system", i.e., "a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist". Three main definitions of resilience – presented below – have progressively emerged and currently coexist in the literature.

Key messages

Resilience theory provides a framework for understanding how social-ecological systems persist, adapt and transform in response to disturbances and changes.

Resilience responses include persistence, recovery, adaptation and transformation. These responses operate at different scales within a system, balancing stability with the capacity for change.

The elusive nature of resilience can be understood through various lenses, each emphasizing a different aspect of system dynamics. These lenses include engineering resilience (which assumes one stable state), ecological resilience (multiple stable states) and evolutionary resilience (transient dynamics far from equilibrium).

Diversity, redundancy, connectivity, integrity, flexibility, participation, effective governance and accountability are critical attributes that strengthen the resilience of social-ecological systems.

Embracing these attributes helps to maintain or build systems capable of navigating uncertainty, promoting diversity, fostering inclusive collaboration, implementing flexible governance structures, and ensuring transparent, accountable decision-making processes.

1.1 Engineering resilience

The first school of thought assumes that one single stable equilibrium exists for the system under study. Resilience, therefore, describes “how fast a variable that has been displaced from equilibrium returns to it.” (Pimm 1991). In a seminal article, Holling (1973) called this kind of resilience “stability” and defined it as “the ability of a system to return to an equilibrium state after a temporary disturbance; the more rapidly it returns and the less it fluctuates, the more stable it would be”. In this definition, resistance to disturbance, the amplitude and frequency of oscillations of the system around the equilibrium (i.e. How close to equilibrium a system stays and how often it changes), time of recovery and speed of return to the equilibrium are the main characteristics of resilience (Holling 1973). This deterministic view of resilience focuses on efficiency, constancy and predictability, and uses command-and-control management systems. For this reason, it is usually called engineering resilience (Holling 1996; Davoudi 2012). This definition can describe a non-linear system only very close to the equilibrium where a linear response is a valid approximation (Folke 2006).

1.2 Ecological resilience

However, scientists have demonstrated that multiple stable states, bounded by thresholds, can exist for a given ecosystem (Folke 2006; Nelson et al. 2007)¹. When such a threshold or “tipping point” is crossed, due to a change in external conditions or in the state of the system itself, the system can switch, sometimes very abruptly, to a totally different stable state and it may be very difficult or even impossible to go back to the initial state at a reasonable cost (van Nes et al. 2016; IPCC 2022). In this context, resilience is defined as the maximum amount of disturbance that a system can support while maintaining its current state, structure and identity, i.e., without crossing the threshold – the “point of no return” (Holling 1996; Walker et al. 2004; Folke 2006; Scheffer et al. 2015). This more probabilistic view of resilience, emerging from ecology science, is generally called ecological resilience. It embraces variability, heterogeneity, non-linearity, thresholds and abrupt changes, uncertainty and surprise (Holling 1986; Folke 2006). Here, resilience is not always a good thing when it creates “social-ecological traps” helping to maintain the system in an undesirable state. This is why resilience is not only about resistance, stability, persistence and recovery, but also about adaptation, reorganization, innovation and transformation – even if these terms may seem mutually contradictory in our common understanding (Carpenter et al. 2001; Walker et al. 2004; Nelson et al. 2007; Folke et al. 2010; Cinner and Barnes 2019; Falk et al. 2019).

1.3 Evolutionary resilience: a continuum of resilience responses

Both engineering and ecological resilience assume the existence of single or multiple stable equilibriums. But, in most of the cases, there might not exist any stable equilibrium at all in complex social-ecological systems. It is most likely that these systems are continuously changing, driven by external forces and/or internal processes, and they might spend most if not all the time in a transient state, far from any equilibrium (Holling 1973; Scheffer 2009; Davoudi 2012; Bahadur et al. 2013). Once disturbed, a system hardly ever bounces back to the exact same state. This introduces chaos, complexity, uncertainty, unpredictability and surprise into the equation. Here, resilience is not defined as a return to normality, but rather as the capacity of complex social-ecological systems to change, adapt and, if necessary, transform in ways that continue to support human well-being under changing conditions, particularly in the face of unexpected change. This definition of resilience has been termed social-ecological (Quinlan et al. 2015; Folke et al. 2016) or evolutionary resilience (Davoudi 2012; Li et al. 2020).

1. This social diversity encompasses diversity in gender, age and race; in levels of income and power; in education, culture and knowledge systems; in perspectives, views, norms and values; as well as the diverse functions they perform in the system (functional social diversity).

Four main resilient responses or strategies emerge from the literature: persistence, recovery, adaptation and transformation (Walker et al. 2004; Nelson et al. 2007; Folke et al. 2010; Béné and Doyen 2018; Cinner and Barnes 2019). These resilience responses may operate at different scales, from individual (or single component) resistance to population (or sub-system) recovery and ecological community (or whole system) reorganization (Falk et al. 2019). They address increasing levels of change and usually come with increasing related social, economic and environmental costs (Béné and Doyen 2018). Following Bruneau et al. (2003), it could thus be said that a resilient system demonstrates the right balance between “strength” or “robustness” (i.e., persistence and recovery) and “flexibility” (i.e., adaptability and transformability), two notions that, at first sight, may seem antinomic.

2. What are the main attributes of resilient systems?

The concept of resilience presented in Section 1 has sometimes been considered a “slippery concept”, firstly because of the different meanings it has assumed in recent decades, and secondly because it is unclear how to translate this theoretical concept (whatever definition is used) into practical strategies and actions on-the-ground, in a specific context (Davoudi 2012; Morecroft et al. 2012; Fisichelli et al. 2016; Béné and Doyen 2018). Many studies, aiming to further operationalize this concept, have therefore tried to identify and describe the main qualities expected to support and enhance resilience in a given social-ecological system.

Based on a rapid literature review, we suggest that resilience of social-ecological systems can be characterized by eight key attributes: diversity, redundancy, connectivity, integrity, flexibility, participation, polycentric and multi-layered governance, and accountability. Each of these are described in the following sections.

2.1 Diversity

Multiple equilibria, instability and movement between states in a system are factors that maintain heterogeneity and diversity – this may provide resilience in the face of unexpected disturbances (Holling 1996). This “insurance hypothesis” predicts that net productivity and resilience are positively correlated with biodiversity and species richness (Yachi and Loreau 1999; Carpenter et al. 2001; Elmqvist et al. 2003; Cumming et al. 2013; Timpane-Padgham et al. 2017). However, a higher number of species in an ecosystem does not automatically lead to higher ecosystem performance and resilience. Indeed, the role of biological diversity in ecosystem functioning and resilience is mediated through functional diversity – the diversity of functional groups in a given ecosystem, which impacts ecosystem performance, as well as response diversity – the variability of species’ responses to a given change within the same functional group, which influences ecosystem resilience (Holling 1996; Elmqvist et al. 2003; Folke 2006; Walker et al. 2006). In social systems, the concept of social diversity is used to characterize the different stakeholder groups involved in the system². Economic diversity is also important for resilience. Economies dominated by a single sector, or by communities depending on a narrow range of resources, will likely be highly vulnerable to a disturbance affecting their dominant sources of livelihoods and income (Norris et al. 2008; Cutter et al. 2010; Bahadur et al. 2013; Quinlan et al. 2015; IPCC 2022).

2.2 Redundancy

Functional redundancy – the capacity of some elements in a system to compensate fully or partially for others – is an insurance that essential system functions can persist even if some “redundant” components are lost or fail (Rosenfeld 2002; Biggs et al. 2012; Bahadur et al. 2013; Pillar et al. 2013;

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Aquilué et al. 2020). However, diversity and redundancy may come with costs for the system's efficiency. Consequently, tracking and removing redundant components, i.e., components that are deemed to be either useless or uncritical, is a widely used way to reduce costs while increasing productivity and efficiency, be it in agroecosystems, industrial processes or governance structures. Therefore, a tension always exists in complex social-ecological systems between efficiency on the one hand, and diversity and redundancy on the otherhand. If levels of redundancy and diversity are too low this risks producing brittle systems that are perhaps highly efficient in a given environment, able to resist to predictable variability and changes in the short term, but with low resilience to unpredictable changes in the long-term. As such, the role of redundancy in resilience depends on the level and predictability of the disturbances experienced by the system. By contrast, levels of redundancy and diversity that are too high may lead to inefficiency and system stagnation, undermining ecosystem productivity and resilience in the long term (Holling 1986, 1996; Walker et al. 2006; Biggs et al. 2012).

2.3 Connectivity

Complex social-ecological systems can be represented as networks where the different components (e.g., habitats, species or actors) are the nodes, and the relationships between them (e.g., predator-prey, competition for resources, pollination, market transactions, partnerships) are the links. Connectivity enhances resilience in ecological systems because it facilitates exchange of information, energy, materials, nutrients, species or genes between nodes, and, more generally, facilitates recovery after a local disturbance. In social systems, continuous connections and interactions contribute to create the trust needed for partnerships and collective action. However, high connectivity can also accelerate the spread of disturbances, such as pests, diseases, invasive species, wildfires or financial crises, across the network nodes, and support homogenization of ecological habitats or adoption of synchronized, yet unsustainable behaviours across actors. This is why network theory suggests that a system is resilient if it strikes the right balance between connectivity, centrality and modularity, i.e., between central coordination and exchange of information on the one hand, and capacity for local innovation or divergent evolution on the other hand (Janssen et al. 2006; Biggs et al. 2012; Timpone-Padgham et al. 2017; Isaac et al. 2018; Aquilué et al. 2020; Li et al. 2020).

2.4 Integrity

Ecological integrity denotes the level of wilderness, pristineness or intactness of an ecosystem. In other words, it assesses how close an ecosystem is to being a "natural" ecosystem, free from any human influence, in terms of species composition and diversity, ecological processes, structure and function. The more an ecosystem is degraded, the lower its ecological integrity. In integral or intact ecosystems, a set of biological, physical and chemical conditions, processes and interactions – if kept within their naturally acceptable variation range³ – enable a balanced, diverse and adaptive community of organisms to persist in the long-term. Ecological integrity is therefore expected to enhance ecosystem resilience, while ecosystem degradation is expected to exacerbate vulnerability (Parrish et al. 2003; Manuel-Navarrete et al. 2004; Theobald 2013; Wurtzebach and Schultz 2016). This notion of ecological integrity, used to describe natural or intact landscapes, may appear less relevant to describe agricultural or forested landscapes that have been shaped over millennia by continuous human-nature interactions and that now cover most of the Earth's land surface. There is no social-ecological equivalent for the concept of ecological integrity. As such, we suggest broadening the notion to call a social-ecological system "integral" or "intact" if it is sustainably productive, resource-use efficient, well-adapted to its environment and, building upon ecosystem

³Parrish et al. (2003) distinguish between "natural" and "acceptable" variation ranges, because what is "natural" might be difficult to define. Where current ecosystems have been so profoundly altered by human activities over long periods of time that they have no historical "pristine" counterpart, the historical variation range can serve as a useful reference. However, under rapidly changing climatic conditions, or in irrevocably degraded ecosystems, even the historical variation range may become irrelevant as a benchmark (Wurtzebach and Schultz 2016; Falk et al. 2019).

services, processes and functions, able to make the most of its environment in the long-term. This definition could apply both to some Indigenous and traditional production systems, as well as to more innovative nature-based solutions.

2.5 Flexibility

Flexibility reflects not only the diversity of available options but also the capacity and willingness of actors in the system to engage in alternative or innovative strategies (Cinner and Barnes 2019). Flexibility is a central condition for both adaptability – i.e., the capacity of actors in a system to deal with uncertainty and change and manage resilience –, and transformability – i.e., the capacity to create a fundamentally new system when the current one becomes untenable (Walker et al. 2004; Bahadur et al. 2013). Self-organization and learning capacity are two qualities that contribute directly to enhance flexibility, adaptability and transformability in social-ecological systems. Self-organization explains how complex structures and patterns can emerge from apparent disorder in complex adaptive systems (Carpenter et al. 2001; Folke 2006; Biggs et al. 2012; Scheffer et al. 2015), building upon diversity, interactions and autonomous processes (Levin 1998), even without system-level intentionality or centralized control (Walker et al. 2006). “Learning-by-doing” through experimentation and learning from each other, in an iterative process filling the gap between knowledge and action, are key pillars of adaptive management (or co-management) strategies (Carpenter et al. 2001; Stringer et al. 2006; Walker et al. 2006; Cumming et al. 2013; Bahadur et al. 2013). The tension that exists between efficiency and flexibility reflects the opposition between two visions of resilience. On one side there are classical management methods corresponding to the mechanistic vision of engineering resilience – these promote optimality, efficiency, stability, risk management, and expert command and control. On the other side, adaptive management methods corresponding to the ecological or social-ecological visions of resilience, consider nonlinear and chaotic dynamics, uncertainty and surprise, and promote diversity, redundancy, flexibility, participation and adaptive learning (Holling 1973, 1986, 1996; Nelson et al. 2007; Leach 2008).

2.6 Participation

Inclusive participation brings to the table different experiences, perspectives, interests, values and beliefs. Deliberation and continuous interactions between the diverse stakeholders involved progressively build mutual trust and shared understanding, reduce the risk of conflict and enhance the legitimacy of decisions made. Participation also fosters social and collaborative learning as well as integration of different forms of scale-specific knowledge (e.g., Indigenous, traditional and local knowledge). As such, broad participation helps progress towards a consensual vision and strategy and mobilize resources and people, thus facilitating self-organization, cooperation and collective action. Large and meaningful participation, within strong institutional settings, is critical for monitoring and experimentation, which are central steps in adaptive management or co-management processes, and for ensuring that the learning and decision-making processes are not captured by the most powerful actors (Lebel et al. 2006; Stringer et al. 2006; Walker et al. 2006; Nelson et al. 2007; Biggs et al. 2012; Bahadur et al. 2013; Cumming et al. 2013; IPCC 2022).

2.7 Polycentric and multi-layered governance

The concept of panarchy refers to cross-scale interactions in complex social-ecological systems. These interactions are viewed as a series of nested adaptive cycles operating and interacting at different spatial or temporal scales (Gunderson and Holling 2002; Walker et al. 2004; Folke 2006; Davoudi 2012; Allen et al. 2014). Scientists advocate for the establishment or strengthening of polycentric and multi-layered governance mechanisms so as to properly address these cross-scale interactions. When compared to more monolithic arrangements, such governance mechanisms foster social learning and experimentation; enable a better match between knowledge and action through iterative processes; and allow more flexible, adaptive and innovative responses to change

at the appropriate scale. Polycentric and multi-layered governance structures require and enable strengthened participation and continuous interactions among actors operating at different scales; appropriate representation to reduce transaction costs and give voice to the most vulnerable groups; strong leadership; as well as efficient coordination, within and across scales, sectors and actors, supported by key “mediating” players, acceptable to all parties (Berkes et al. 2003; Lebel et al. 2006; Stringer et al. 2006; Walker et al. 2006; Nelson et al. 2007; Folke et al. 2007; Biggs et al. 2012; Cumming et al. 2013; Bahadur et al. 2013; Cinner and Barnes 2019; IPCC 2022).

2.8 Accountability

Broadened participation and strong polycentric and multi-layered governance mechanisms cannot effectively strengthen resilience without accountability. Accountability means that authorities are responsible for their acts in front of both the other stakeholders involved or affected, and the general public. This implies full transparency in the provision and exchange of information and explanation of decisions made; independent monitoring and evaluation; independent mechanisms of control and sanction; separation of powers; free media and freedom of expression. Accountability must occur both in vertical and in more horizontal relationships, as a protection against elite capture of agenda and resources. Effective accountability supports equity, social justice and a fair repartition of risks and benefits. It contributes to empowering the most vulnerable segments of society and protecting their rights and interests, thus preventing conflicts and reducing the vulnerability of the whole social-ecological system (Lebel et al. 2006; Biggs et al. 2012).

3. Conclusion

At its core, resilience entails the ability of systems to maintain essential structure and functions while under various stressors. Resilience is not just about bouncing back from disruptions but also about thriving under changing conditions and embracing transformation when necessary. Resilience thinking offers a robust framework for social-ecological system managers to navigate complexity, non-linear dynamics, uncertainties and challenges. This involves understanding resilience through multiple perspectives, including engineering, ecological and evolutionary resilience, and embracing a range of resilience responses, from persistence and recovery to adaptation and transformation, operating across different spatial and temporal scales within the system.

Social-ecological systems face manifold challenges such as water scarcity, degradation and biodiversity loss, and climate change impacts. Embracing resilience principles is crucial for their sustainable management. The role of ecosystem managers (including protection agencies, forestry and agriculture departments, private companies, civil society organizations, local communities, research institutions and practitioners on the ground) is pivotal in safeguarding the resilience of these systems for future generations. By prioritizing key resilience attributes – diversity, redundancy, connectivity, integrity, flexibility, participation, polycentric and multi-layered governance and accountability – managers can effectively navigate uncertainties and disturbances while promoting ecosystem health and human well-being in the long term. By working collaboratively across sectors and scales, and engaging diverse stakeholders in decision-making processes, managers can build adaptive capacity and foster resilience in the face of complex and often unpredictable challenges.

4. References

- Allen CR, Angeler DG, Garmestani AS, Gunderson LH, Holling CS. 2014. Panarchy: Theory and application. *Ecosystems* 17: 578–589. <https://doi.org/10.1007/s10021-013-9744-2>
- Aquilué N, Filotas É, Craven D, Fortin MJ, Brotons L, Messier C. 2020. Evaluating forest resilience to global threats using functional response traits and network properties. *Ecological Applications* 30(5): e02095. <https://doi.org/10.1002/eap.2095>
- Bahadur AV, Ibrahim M, Tanner T. 2013. Characterising resilience: Unpacking the concept for tackling climate change and development. *Climate and Development* 5(1): 55–65. <https://doi.org/10.1080/17565529.2012.762334>
- Béné C and Doyen L. 2018. From resistance to transformation: A generic metric of resilience through viability. *Earth's Future* 6(7): 979–996. <https://doi.org/10.1002/2017EF000660>
- Berkes F and Folke C. eds. 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. New York: Cambridge University Press. <https://www.cambridge.org/vi/universitypress/subjects/life-sciences/ecology-and-conservation/linking-social-and-ecological-systems-management-practices-and-social-mechanisms-building-resilience?format=PB>
- Berkes F, Colding J, Folke C. eds. 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge, UK: Cambridge University Press. <https://doi.org/10.1017/CBO9780511541957>
- Biggs R, Schlüter M, Biggs D, Bohensky EL, BurnSilver S, Cundill G, Dakos V, Daw TM, Evans LS, Kotschy K, et al. 2012. Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources* 37: 421–448. <https://doi.org/10.1146/annurev-environ-051211-123836>
- Bruneau M, Chang SE, Eguchi RT, Lee GC, O'Rourke TD, Reinhorn AM, Shinozuka M, Tierney K, Wallace WA, von Winterfeldt D. 2003. A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra* 19(4): 733–752. <https://doi.org/10.1193/1.1623497>
- Carpenter S, Walker B, Anderies JM, Abel N. 2001. From metaphor to measurement: Resilience of what to what? *Ecosystems* 4: 765–781. <https://doi.org/10.1007/s10021-001-0045-9>
- CE (Council of Europe). 2000. *Council of Europe Landscape Convention*. As amended by the 2016 Protocol. European Treaty Series. No. 176. Florence. <https://rm.coe.int/16807b6bc7>
- Cinner JE and Barnes ML. 2019. Social dimensions of resilience in social-ecological systems. *One Earth* 1(1): 51–56. <https://doi.org/10.1016/j.oneear.2019.08.003>
- Cumming GS, Olsson P, Chapin FS, Holling CS. 2013. Resilience, experimentation and scale mismatches in social-ecological landscapes. *Landscape Ecology* 28: 1139–1150. <https://doi.org/10.1007/s10980-012-9725-4>
- Cutter S, Burton C, Emrich C. 2010. Disaster resilience indicators for benchmarking baseline conditions. *Journal of Homeland Security and Emergency Management* 7(1): 1–22. <https://doi.org/10.2202/1547-7355.1732>
- Davoudi S. 2012. Resilience: A bridging concept or a dead end? *Planning Theory & Practice* 13(2): 299–307. <https://doi.org/10.1080/14649357.2012.677124>
- Elmqvist T, Folke C, Nyström M, Peterson G, Bengtsson J, Walker B, Norberg J. 2003. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment* 1(9): 488–494. <https://doi.org/10.2307/3868116>
- Falk DA, Watts AC, Thode AE. 2019. Scaling ecological resilience. *Frontiers in Ecology and Evolution* 7: 275. <https://doi.org/10.3389/fevo.2019.00275>
- Fisichelli NA, Schuurman GW, Hoffman CH. 2016. Is 'resilience' maladaptive? Towards an accurate lexicon for climate change adaptation. *Environmental Management* 57(4): 753–758. <https://doi.org/10.1007/s00267-015-0650-6>
- Folke C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16(3): 253–267. <https://doi.org/10.1016/j.gloenvcha.2006.04.002>
- Folke C, Biggs R, Norström AV, Reyers B, Rockström J. 2016. Social-ecological resilience and biosphere-based sustainability science. *Ecology & Society* 21(3): 41. <https://doi.org/10.5751/ES-08748-210341>
- Folke C, Carpenter SR, Walker B, Scheffer M, Chapin, Rockström J. 2010. Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology & Society* 15(4): 20. <https://www.ecologyandsociety.org/vol15/iss4/art20/>
- Folke C, Pritchard L Jr, Berkes F, Colding J, Svedin U. 2007. The problem of fit between ecosystems and institutions: Ten years later. *Ecology & Society* 12(1): 30. <https://www.ecologyandsociety.org/vol12/iss1/art30/>
- Gunderson LH and Holling CS. eds. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press. ISBN 1-55963-857-5. <https://islandpress.org/books/panarchy>
- Holling CS. 1996. Engineering resilience versus ecological resilience. In Schulze P. ed. *Engineering Within Ecological Constraints*. Washington, DC: National Academy Press 31–44. <https://nap.nationalacademies.org/read/4919/chapter/4#33>
- Holling CS. 1986. The resilience of terrestrial ecosystems: Local surprise and global change. In Clark WC and Munn RE. eds. *Sustainable Development of the Biosphere*. London: Cambridge University Press 92–317. <https://pure.iiasa.ac.at/2751>
- Holling CS. 1973. Resilience and stability of ecological systems. *Annual Review of Ecological Systems* 4:1–23. <https://doi.org/10.1146/annurev.es.04.110173.000245>
- IPCC (Intergovernmental Panel on Climate Change). 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, et al. eds. Cambridge, UK and New York: Cambridge University Press 3056. <https://doi.org/10.1017/9781009325844>

- Isaac NJB, Brotherton PNN, Bullock JM, Gregory RD, Boehning-Gaese K, Connor B, Crick HQP, Freckleton RP, Gill JA, Hails RS, et al. 2018. Defining and delivering resilient ecological networks: Nature conservation in England. *Journal of Applied Ecology* 55(6): 2537–2543. <https://doi.org/10.1111/1365-2664.13196>
- Janssen MA, Bodin Ö, Anderies JM, Elmqvist T, Ernstson H, McAllister RRJ, Olsson P, Ryan P. 2006. Toward a network perspective of the study of resilience in social-ecological systems. *Ecology & Society* 11(1):15. <https://www.jstor.org/stable/26267803>
- Leach M. 2008. Re-framing Resilience: A Symposium Report. STEPS Working Paper 13. Brighton, UK: STEPS Centre 22. <https://steps-centre.org/wp-content/uploads/Resilience.pdf>
- Lebel L, Anderies JM, Campbell BM, Folke C, Hatfield-Dodds S, Hughes TP, Wilson J. Governance and the capacity to manage resilience in social-ecological systems. *Ecology & Society* 11(1):19. <https://doi.org/10.5751/ES-01606-110119>
- Levin SA. 1998. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems* 1: 431–436. <https://doi.org/10.1007/s100219900037>
- Li T, Dong Y, Liu Z. 2020. A review of social-ecological system resilience: Mechanism, assessment and management. *Science of The Total Environment* 723: 138113. <https://doi.org/10.1016/j.scitotenv.2020.138113>
- Manuel-Navarrete D, Kay JJ, Dolderman D. 2004. Ecological integrity discourses: Linking ecology with cultural transformation. *Human Ecology Review* 11(3): 215–229. <https://apjh.humanecologyreview.org/pastissues/her113/navarretekaydolderman.pdf>
- Morecroft MD, Crick HQ, Duffield SJ, Macgregor NA. 2012. Resilience to climate change: Translating principles into practice. *Journal of Applied Ecology* 49(3): 547–551. <https://www.jstor.org/stable/23259051>
- Nelson DR, Adger WN, Brown K. 2007. Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources* 32(1): 395–419. <https://doi.org/10.1146/annurev.energy.32.051807.090348>
- Norris FH, Stevens SP, Pfefferbaum B, Wyche KF, Pfefferbaum RL. 2008. Community resilience as a metaphor, theory, set of capacities and strategy for disaster readiness. *American Journal of Community Psychology* 41(1–2): 127–150. <https://doi.org/10.1007/s10464-007-9156-6>
- Parrish JD, Braun DP, Unnasch RS. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. *BioScience* 53(9): 851–860. [https://doi.org/10.1641/0006-3568\(2003\)053\[0851:AWCWWS\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2003)053[0851:AWCWWS]2.0.CO;2)
- Pillar VD, Blanco CC, Müller SC, Sosinski EE, Joner F, Duarte LDS. 2013. Functional redundancy and stability in plant communities. *Journal of Vegetation Science* 24(5): 963–974. <https://doi.org/10.1111/jvs.12047>
- Pimm SL. 1991. The Balance of Nature? Ecological Issues in the Conservation of Species and Communities. *Oryx* 27(2): 125–126. <https://doi.org/10.1017/S0030605300020731>
- Quinlan AE, Barbés-Blázquez M, Haider LJ, Peterson GD. 2015. Measuring and assessing resilience: Broadening understanding through multiple disciplinary perspectives. *Journal of Applied Ecology* 53(3): 677–687. <https://doi.org/10.1111/1365-2664.12550>
- Rosenfeld JS. 2002. Functional redundancy in ecology and conservation. *Oikos* 98(1): 156–162. <https://doi.org/10.1034/j.1600-0706.2002.980116.x>
- Scheffer M. 2009. *Critical Transitions in Nature and Society*. Princeton University Press: Princeton, NJ. <https://press.princeton.edu/books/paperback/9780691122045/critical-transitions-in-nature-and-society>
- Scheffer M, Carpenter SR, Dakos V, van Nes EH. 2015. Generic indicators of ecological resilience: Inferring the chance of a critical transition. *Annual Review of Ecology, Evolution, and Systematics* 46: 145–167. <https://doi.org/10.1146/annurev-ecolsys-112414-054242>
- Stringer LC, Dougill AJ, Fraser E, Hubacek K, Prell C, Reed MS. 2006. Unpacking “participation” in the adaptive management of social-ecological systems: A critical review. *Ecology & Society* 11(2): 39. <https://www.ecologyandsociety.org/vol11/iss2/art39/>
- Theobald DM. 2013. A general model to quantify ecological integrity for landscape assessments and US application. *Landscape Ecology* 28: 1859–1874. <https://doi.org/10.1007/s10980-013-9941-6>
- Timpane-Padgham BL, Beechie T, Klinger T. 2017. A systematic review of ecological attributes that confer resilience to climate change in environmental restoration. *PLoS ONE* 12(3): e0173812. <https://doi.org/10.1371/journal.pone.0173812>
- van Nes EH, Arani BMS, Staal A, van der Bolt B, Flores BM, Bathiany S, Scheffer M. 2016: What do you mean, ‘tipping point’? *Trends in Ecology & Evolution* 31(12): 902–904. <https://doi.org/10.1016/j.tree.2016.09.011>
- Walker B and Salt D. 2006. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Washington, DC: Island Press. <https://islandpress.org/books/resilience-thinking>
- Walker B, Gunderson LH, Kinzig A, Folke C, Carpenter S, Schultz L. 2006. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society* 11(1):13. <http://www.ecologyandsociety.org/vol11/iss1/art13/>
- Walker B, Holling CS, Carpenter SR, Kinzig A. 2004. Resilience, adaptability and transformability in social-ecological systems. *Ecology and society* 9(2):5. <https://www.ecologyandsociety.org/vol9/iss2/art5/>
- Wurtzebach Z, Schultz C. 2016. Measuring ecological integrity: History, practical applications and research opportunities. *BioScience* 66(6): 446–457. <https://doi.org/10.1093/biosci/biw037>
- Yachi S and Loreau M. 1999. Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *Proceedings of the National Academy of Science of the United States of America* 96(4): 1463–1468. <https://www.jstor.org/stable/47224>



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